ATTRIBUTING EXTREME WEATHER

THE NEW SCIENCE OF EXTREME EVENT ATTRIBUTION

Since 1970, extreme weather hazards have occurred every day, on average, over the past 50 years, according to the World Meteorological Organization. Being able to link such hazards to climate change and do so quickly can be an incredibly powerful tool to communicate the urgency and consequences of global warming. The emerging science of extreme event attribution utilizes mathematical approaches to tease out whether and by how much human-caused climate change contributed to individual extreme events. Attribution science has matured to the point where the number and intensity of extreme weather hazards caused by climate change can now be estimated.

CAN I BLAME CLIMATE CHANGE?

The number of extreme weather events has increased fivefold over the last 50 years, driven primarily by climate change. It's only normal for someone affected by a disaster to ask if it was a natural event or a man-made event because of global warming. While trends in vulnerability and exposure are major drivers of disaster impacts, the relatively new technique known as detection and attribution provides quantitative information on the probability and magnitudes of extreme events. Much like an epidemiologist tries to identify the causal factors that contribute to the development or prevention of disease, attribution scientists use mathematical models to test whether — and by how much — human-caused global warming played a part in an extreme weather event.

The science of extreme weather event attribution began after a 2003 heat wave killed as many as 70,000 people across Europe. It was an event hotter than anything recorded on the continent in 500 years. Until that point, detection and attribution studies were limited to quantifying the long-term changes in climate variables, most notably temperature or extreme precipitation. Climate scientists shied away from probing the human effects on individual events. When asked, they'd respond with statements like, "We can't say about this particular event, but such changes are what we would expect." Today, quantitative attribution statements are routinely made for an ever-increasing variety of individual extreme weather events.

KEY MESSAGES

- ☑ The number of extreme weather hazards has been increasing over the past 50 years.
- ☑ It is now possible, through extreme event attribution methods, to make quantitative statements about the influence of human-induced global warming on specific individual extreme weather events.
- ☑ Extreme event attribution is a formal use of causal inference techniques. Confidence in resulting attribution statements is enhanced when multiple methods, mathematical models, and data sources lead to similar conclusions. These conclusions can be powerful tools for adapting behaviors and infrastructure to climate change.
- ☑ Causal inference together with an understanding of the key physical processes has revealed that the human influence on the climate system, including extreme weather, is indisputable.

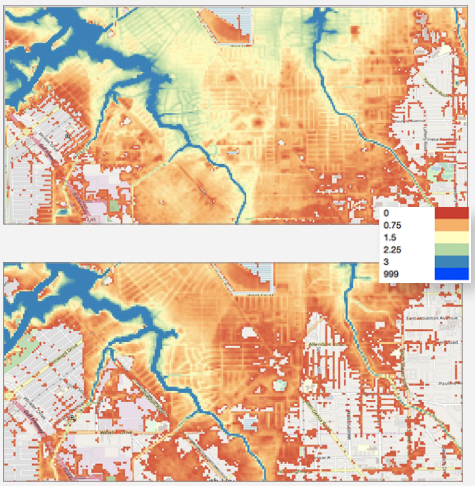
MORE PRECISE RESULTS

Using statistical causal inference, attribution scientists ask two related questions: "Did climate change affect the probability of the occurrence of an event of the observed magnitude?" and "Did climate change affect the magnitude of events of a rarity similar to that observed?" Two classes of causal inference methods can be used to answer these questions.

Pearl causality requires an *i*nterference, often a placebo in clinical medical trials. As there is only one Earth, attribution scientists use climate models instead. Simulations of the actual climate, configured as realistically as possible, are compared to equivalent counterfactual simulations where human contributions to greenhouse gases are removed.

A second class of causal inference statements without interference can be made from the observed data alone. Granger causality is demonstrated by constructing statistical models that utilize parameters to represent natural and human influences. Significance testing of these parameters can reveal their relative roles in the frequency and magnitude of extreme weather events. However, as simple correlation alone does not imply causality, there must be a sound physical mechanism to reinforce any conclusions.

CASE STUDY: HURRICANE HARVEY IN HOUSTON, TEXAS



Event attribution studies of severe storms are a recent development. The first tropical cyclone attribution statements were made in 2017 about Hurricane Harvey, a devastating Category 4 hurricane that made landfall on the United States' Texas coast. The storm dumped a year's worth of rain in less than a week on the city of Houston, where one out of every 4.7 residents lives in poverty.

Three independent groups concluded that global warming significantly increased the storm's precipitation and subsequent flooding. Before these studies, most specialists, including this author, felt that the human-induced increases in extreme precipitation would be dictated by thermodynamics and constrained to roughly 7% per degree Centigrade warming, as dictated by the 19th century Clausius-Clapeyron relationship. However, analysis of Harvey and other hurricanes finds that extreme tropical cyclone precipitation increases with warming at a rate substantially greater than thermodynamics alone, revealing that dynamical processes are also important.

Top: Simulation of the depth of the actual Hurricane Harvey flood in the South Houston neighborhood. **Bottom:** Simulation of the counterfactual Hurricane Harvey flood without the current amount of climate change.

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For the deadly 2003 European heat wave, a group of scientists in the United Kingdom found that such extreme heats were twice as likely with climate change than without, answering the first attribution question. Now, nearly 20 years later, unabated global warming has increased the risk of such heat waves by a factor of ten or more. For the second attribution question, it's estimated that climate change increased the temperature of such rare heat waves from about 0.5°C in 2003 to about 2°C in 2021.

The degree to which global warming alters the risk of a particular heat wave varies. For instance, the 2015 heat wave in Pakistan was both hot and very humid. In high humidity, the air is saturated with water vapor, limiting the evaporative cooling effect of sweating. Attribution scientists concluded that climate change increased the chances of that event by at least a factor of 1,000. It's fair to say that all recent and future extreme heat waves are or will be made more severe by the current levels of climate change.

Extension of statistical causal inference to storms, droughts, and other extreme weather has provided similar information about the role of climate change in these hazards.

COMMUNICATING THE RISKS

Results of attribution studies can provide persuasive evidence of the urgency — and the catastrophic consequences — of climate change and inform decisions about managing risk and selecting adaptation strategies. For example, flood maps that fail to account for climate change are likely to underestimate the actual flood risk. Similarly, the risk to property and life from increased heat wave temperatures and hurricane intensities can be quantified by event attribution.

But as for any causal inference statement, it is important to realize the underlying statistical framing of extreme weather event attribution. Hence, blaming climate change for damage from an extreme event can be correct in a probabilistic sense. Attribution studies also help climate scientists improve their understanding of the physical mechanism of changes in extreme weather as the climate warms. This second purpose is reflected in the IPCC 6th Assessment Report "It is indisputable that human activities are causing climate change, making extreme climate events, including heat waves, heavy rainfall, and droughts, more frequent and severe."

CONCLUSIONS

As the climate continues to warm, the human influence on the severity and risk of extreme weather becomes larger, and attribution statements about extreme weather events are useful for developing strategies to help control vulnerability and exposure and better prevent disasters.

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